

# Naval Surface Warfare Center Carderock Division

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Center for Innovation in Ship Design

Technical Report

## Heavy Lift Army Landing Craft

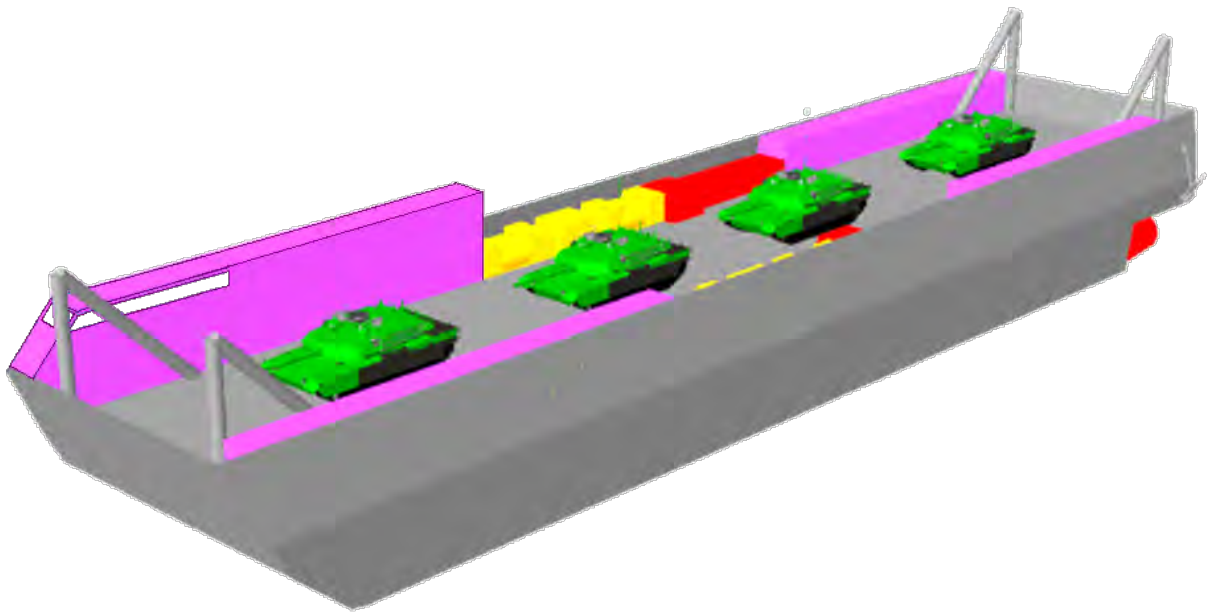
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## **Abstract**

Landing craft are used to quickly transport cargo to areas where larger ships are unable to reach due to beach gradient limitations or lack of an adequate port. The current landing craft of the U.S. Army are limited by poor seakeeping capabilities and they must operate at very low speeds, unloaded and fully loaded.

The goal of the Heavy Lift Army Landing Craft (HLALC) project is to develop a concept design to replace existing Army landing craft such as the Landing Craft Utility (LCU) 2000. The HLALC will operate at a sustained speed of 25 kts while carrying a full load of 300 mt. The project proposes a Surface Effect Ship (SES) landing craft for its speed and seakeeping while maintaining a low draft and large deck area for payload. The HLALC is a rugged craft utilizing proven robust technologies with overall low maintenance.

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# Table of Contents

Abstract.....	ii
Acknowledgements .....	iii
Table of Contents .....	iv
List of Figures .....	v
List of Tables.....	v
List of Abbreviations and Acronyms .....	vi
Executive Summary .....	1
Introduction .....	2
Objective .....	2
Background.....	2
Mission .....	3
Cargo Carrying Capabilities .....	3
Joint Service Requirements .....	3
Concept Development.....	4
Hullform .....	4
Specific Hull Design .....	4
Hull Structural Material .....	5
Hull Structural Evaluation .....	6
Propulsion .....	6
Concept Design.....	7
Principal Characteristics.....	7
General Arrangements .....	7
Twin Hulls .....	8
Cargo Deck.....	8
Accommodations .....	9
Ramp .....	9
Propulsion .....	10
Concept Design Drivers .....	10
Powering Considerations .....	11
Engine Selection.....	11
Propulsor Selection .....	12
Auxiliary systems .....	12
Lift Fan Selection.....	12
Generators.....	12
Range and Fuel .....	13
Weight Estimation .....	14
Stability .....	15
Conclusion .....	15
Summary.....	15
Future Work .....	16
What We Learned .....	16
References.....	18
Appendix A: Initial Brief .....	20
Introduction .....	20
Aim.....	20
Ship Design Requirements.....	21
Areas of Technology Exploration.....	21

Constraints.....	21
Approach.....	22
Deliverables .....	22
Appendix B: PACSCAT Reference Data .....	23
Appendix C: Ramp Deployment .....	27
Appendix D: Personnel Space Requirements .....	28
Appendix E: HLALC Detailed Weight Breakdown .....	30

## **List of Figures**

Figure 1: PACSCAT Hullform.....	5
Figure 2: Perspective View of HLALC .....	8
Figure 3: Inboard Profile Starboard Side Hull.....	8
Figure 4: Plan View of HLALC .....	9
Figure 5: HLALC Powering Requirements .....	11
Figure 6: HLALC Operating Range .....	13

## **List of Tables**

Table 1: HLALC Characteristics .....	7
Table 2: HLALC One-Digit Weight Summary .....	15

## List of Abbreviations and Acronyms

ABS	American Bureau of Shipping
ACV	Air Cushion Vehicle
CISD	Center for Innovation in Ship Design
CONUS	Continental U.S.
DDS	Design Data Standard
DWL	Design Water Line
FLC	Fast Landing Craft
FLD	Full Load Displacement
GM	Distance from Center of Gravity to Metacenter
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HSC	High Speed Connector
HVAC	Heating, Ventilation, and Air Conditioning
ISO	International Standards Organization
kg/kW-hr	Kilogram per Kilowatt-Hour
kts	Knots
kW	Kilowatt
LC	Landing Craft
LCAC	Landing Craft Air Cushion
LCU	Landing Craft Utility
LMSR	Large, Medium Speed Ro/Ro
Lo/Lo	Lift-on/Lift-off
M	Metacenter
m	Meters
MLP	Mobile Landing Platform
MSC	Military Sealift Command
mt	Metric Ton
MW	Megawatt
nm	Nautical Miles
NREIP	Naval Research Enterprise Intern Program
ONR	Office of Naval Research
PACSCAT	Partial Air Cushion Supported Catamaran
Ro/Ro	Roll-on/Roll-off
RTCH	Rough Terrain Container Handler
SES	Surface Effect Ship
SS	Sea State
SWATH	Small Waterplane Area Twin Hull
SWBS	Ship Work Breakdown Structure
T-Craft	Transformable Craft

# Executive Summary

The Heavy Lift Army Landing Craft (HLALC) is intended to allow the Army to provide sustainment to their troops located in benign environments with austere or no ports. In missions where a natural disaster or enemy action has damaged or destroyed ports, the HLALC will be able to access the limited port facilities to deliver supplies to the area.

To make these logistics missions most effective, the craft has to be capable of reaching its destination in a timely manner and through various sea states. To solve this problem, the project team examined the capabilities of the Office of Naval Research's (ONR) Transformable Craft (T-Craft) concept, which has these capabilities. While the large payload and rapid self deployment of T-Craft were attractive; the amphibious and high speed capabilities were not needed for the Army mission. The HLALC incorporates the capabilities of the T-Craft which were important to the Army's sustainment mission while eliminating those capabilities deemed unnecessary. The HLALC was designed as an SES based on the Partial Air Cushion Supported Catamaran (PACSCAT) hullform to provide cargo capacity similar to the T-Craft but without the Air Cushion Vehicle (ACV) capability.

The HLALC is 67.3 m long with a 15 m beam and a 2.1 m draft while on cushion. The Full Load Displacement (FLD) of the HLALC is 1,566 mt. It has a range of 2,500 nm at a sustained speed of 25 kts while fully loaded. It has the capability to carry a 300 mt payload, which is the weight equivalent of four M1A1 tanks. It is equipped to provide basic needs for 50 vehicle handlers (troops) for the delivery mission. The HLALC has accommodations for the operating crew of 10-12 for the duration of the 30 day self-deployment mission.

The HLALC is powered by diesel engines for propulsion and powering the lift fans. The craft has separate diesel generators to provide hotel power. The maximum range of the HLALC is 5,800 nm at 23 kts, achieved by replacing in the entire cargo load with fuel.



# **Introduction**

## **Objective**

The goal of this project was to develop a concept for a rugged low maintenance landing craft that could deliver cargo to the shoreline, but not go over the beach. The HLALC will have to be able to deliver various types of cargo to and from areas with austere or no ports. The original requirements are shown in Appendix A. Subsequent discussion with Army personnel expanded the requirements to include a capability to self deploy at higher speed while carrying the maximum cargo.

## **Background**

Current landing craft, such as the LCU 2000, are slow (10-12 kts) and have poor seakeeping. The LCU 2000 hullform would require so much additional power to reach high speeds that the craft would be unaffordable.

The ONR T-Craft program has developed ship concepts that overcome these limitations. The T-Craft is designed as a SES that can transform into a fully amphibious landing craft, meaning it can travel onto land as an ACV. While operating as an SES, the T-Craft can reach speeds up to 40 kts while carrying its payload of 300 mt. While it has adequate payload for Army missions, the T-Craft has more speed than required and amphibious capabilities that are not needed.

The Partial Air Cushion Supported Catamaran (PACSCAT) variant of an SES offers good seakeeping as well as large deck area, both of which are needed to accomplish the Army's mission. In addition, PACSCAT designs are simple, robust, and are compatible with the Army logistical infrastructure. There have been several design studies on the PACSCAT hullform. A 175 mt PACSCAT landing craft has been built for the United Kingdom's Ministry of Defense, and has completed builder's trials. Scale model testing and operation of large scale demonstrators have shown it to be a scalable hullform. The studies also recommend that steel be used as the hull material. By basing the HLALC on the PACSCAT, there was ample data available for use in the engineering development of the HLALC and for related parametric analyses.

The HLALC fills the performance gap between the current LCU 2000 and the future T-Craft. It has more speed capability than the LCU 2000, while carrying the same payload as the T-Craft without its cost or complexity. The HLALC can provide more efficient sustainment to Army, Navy, and Marine Corps troops in joint operations.

## **Mission**

The HLALC has been tasked with two basic mission profiles. First is the deployment mission which requires self-sustainment capability for up to 30 days (for a crew of 10-12) while the HLALC deploys from the Continental US (CONUS) to an advanced base or from the advanced base into the theater of operations. During the self-deploying mission, the craft must be capable of sustaining speeds between 22-24 kts while carrying a payload of 300 mt over 2,500 nm. The second mission is the delivery mission. The delivery mission is the connection between the advanced base and the beach or an unimproved port. This mission requires the craft to carry the full 300 mt payload for 250 nm at 25 kts while providing limited accommodations for 50 vehicle operators and cargo handlers such as airline style seating, mess, and sanitary facilities.

### **Cargo Carrying Capabilities**

The HLALC will be able to carry 300 mt of cargo, or the weight equivalent of four M1A1 tanks. While the cargo capacity is based on the weight of the four M1A1 tanks, the space for the cargo is not. The HLALC will have a cargo area of 650 m<sup>2</sup>. The types of cargo that will be transported by the HLALC include Roll-on/Roll-off (Ro/Ro) cargo, such as the M1A1 tanks and High Mobility Multipurpose Wheeled Vehicles (HMMWVs), and palletized or containerized cargo, such as International Standards Organization (ISO) containers. The HLALC design has a drive-through cargo deck to facilitate the off-loading of Ro/Ro cargo. The cargo deck is uncovered to accommodate the handling of Lift-on/Lift-off (Lo/Lo) cargo.

### **Joint Service Requirements**

The HLALC could easily be used as a joint service vessel. A broad study would need to be undertaken to see if the HLALC could be used effectively by the Navy and the Marine Corps in their seabasing strategies. Although not addressed in this study, minor changes to the design would enable it to interface with the Navy's Sea Base. Therefore, the HLALC should be very capable as a joint service vessel, enabling all the services to transport cargo, vehicles, or troops to the shore and back again for sustainment purposes.

# Concept Development

## Hullform

The hullforms considered for the HLALC included the Monohull, Small Waterplane Area Twin Hull (SWATH), Catamaran, T-Craft, and SES.

The Monohull was discarded even though many of the current landing craft are monohulls. Monohulls require a flat bottom and a rectangular plan form to achieve the low draft required for a landing craft, which does not lead to good seakeeping characteristics. The flat rectangular shape also has high wave resistance, which requires too much power to reach high speeds, thus making it difficult to achieve long unrefueled ranges at high speeds. HLALC requirements for the deployment mission would necessitate a more slender hull and deeper draft to improve seakeeping and fuel efficiency. Likewise, the HLALC was required by the delivery mission to be beachable, thus dictating a wide and shallow draft. Since the Monohull could not be optimized to meet both requirements, it was discarded on account of its inefficiency as a hullform to meet the dual mission capabilities.

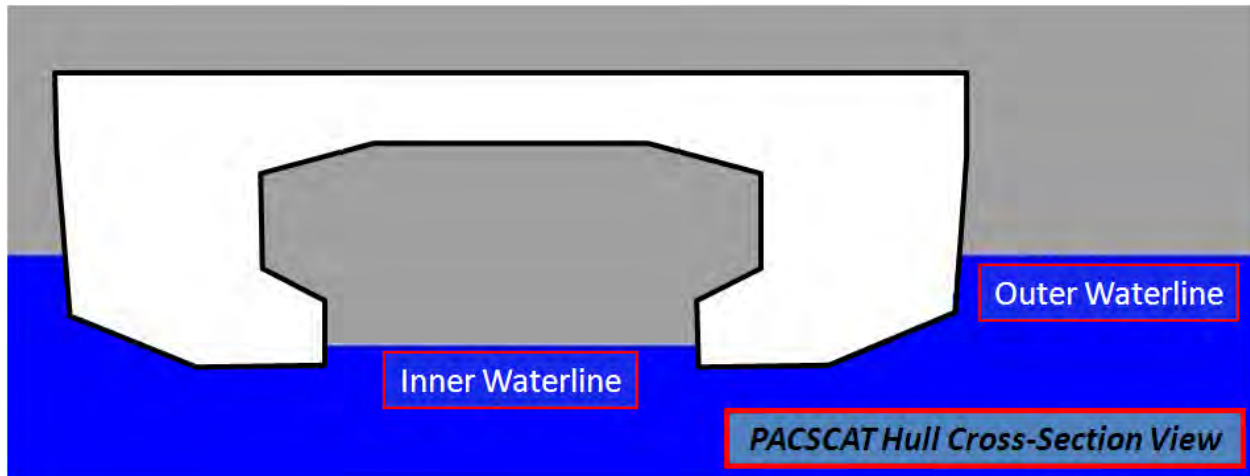
The SWATH was discarded because their draft is deeper than a comparable solution utilizing a Catamaran or SES.

The Army showed great interest in the T-Craft's SES/ACV concept but did not want the complexity associated with the ACV mode. While this hullform was rejected, attributes such as the lift capability, speed, and cargo capacity were attractive for the HLALC.

The PACSCAT variant of an SES was chosen as the hullform because it could be optimized to meet the Army's requirements.

## Specific Hull Design

The PACSCAT hullform differs from other types of SES, in that it relies upon hull buoyancy to support a large fraction (35-50%) of the weight. This hullform provided the desired attributes of the T-Craft without the complexity of the ACV mode. Figure 1 shows the unique PACSCAT hullform.



**Figure 1: PACSCAT Hullform**

Reduced frictional resistance due to partial air cushion support reduces the amount of fuel needed to meet the range requirements of the HLALC. SES's are also known for having good seakeeping properties. This is due to sitting high out of the water and being able to dynamically damp wave-induced motions through active management of the cushion pressure. In addition, the ability of SES's to actively reduce draft becomes a major consideration when trying to beach the craft in very shallow water. Landing craft-size SES's are able to reduce draft at the bow below 1 m, which could allow unloading on any beach where the offloading equipment can ford 1 m of water. Also, since the SES lift capacity is not driven by deck area, there will typically be adequate cargo deck area available.

Availability of the data from three different PACSCAT concepts was invaluable to support the design process and provided confidence in the HLALC design. The three concepts are the Fast Landing Craft (FLC) Concept A, FLC Concept B, and the High Speed Connector (HSC) PACSCAT. General characteristics and weight data for each of those concepts is provided in Appendix B.

## **Hull Structural Material**

In order for the maintenance requirements of the HLALC to be acceptable to the Army, the hull material had to be common and familiar to the Army maintenance infrastructure. Composite materials and titanium were immediately ruled out, leaving aluminum and steel. Selection of steel as the structural material for the hull of the HLALC was mainly driven by three factors. The first two were the Army's desire to make the craft easily maintainable and robust. The Army's present maintenance infrastructure is very familiar with maintaining steel structures. The steel hull is also robust and offers excellent capability to handle the beaching loads. The third factor

was the selection of the PACSCAT hullform, which mitigates the increase in propulsion power resulting from the additional weight of a steel hull. As a result, the weight penalty does not affect the engine sizing or fuel load as much as it would in a high speed craft. The PACSCAT hulls are typically designed with sufficient buoyancy to support 35 to 50% of the craft full load displacement. This is a much higher buoyancy factor than is typical of an SES and, as a result, a PACSCAT has less powerful lift fans that consume less fuel. The fact that the HLALC is a medium speed craft (20-25 kts) also reduces the resistance penalty due to higher structural weight.

## **Hull Structural Evaluation**

The HLALC structure was parametrically scaled from the three PACSCAT designs. The resulting HLALC structure was similar to if not heavier than the other PACSCAT designs. The cross deck structure that supports the vehicle deck and ties the two side hulls together is critical to the design. By linear scaling techniques, it was determined that the HLALC needed to have a minimum of 1.5 m cross-sectional height. Subsequently, it was determined that the spaces in the cross-deck structure could be used for functional purposes (stores, storage, service spaces, accommodations, etc) if the cross-sectional height were raised to 3 m. This cross-sectional height increase enabled a subsequent decision to house the one-piece ramp in a tunnel built in the cross-deck structure. By comparison, the 3 m new cross-deck structure exceeds the relationships established by the original PACSCAT HSC and FLC concepts. It also gives the HLALC a larger ratio of cross-sectional height to length (which is an indication of the craft's ability to handle the transverse bending moment) and a larger ratio of cross-sectional height to beam (which gives some indication of the craft's ability to handle the longitudinal bending moment). While the structural design needs to be developed further, it appears that the concept is achievable.

## **Propulsion**

Gas turbines and diesel engines were considered for the HLALC. Though more expensive than diesel engines, gas turbines are small and would fit better because of the limited space in the hulls of an SES. However, diesel engines were selected because of the Army's preference for the diesel engine over gas turbines. In the current Army infrastructure, they generally do not teach the maintenance of gas turbines (other than for M1A1 tanks), so this technology would be less acceptable to them than diesel engines.

The HLALC propulsion power requirement is small enough to be met with medium-speed diesel engines that fit into the side hulls of the craft. For consistency in

the type of fuel used on the craft, diesel engines were also selected to power the lift fans and electrical generators.

## Concept Design

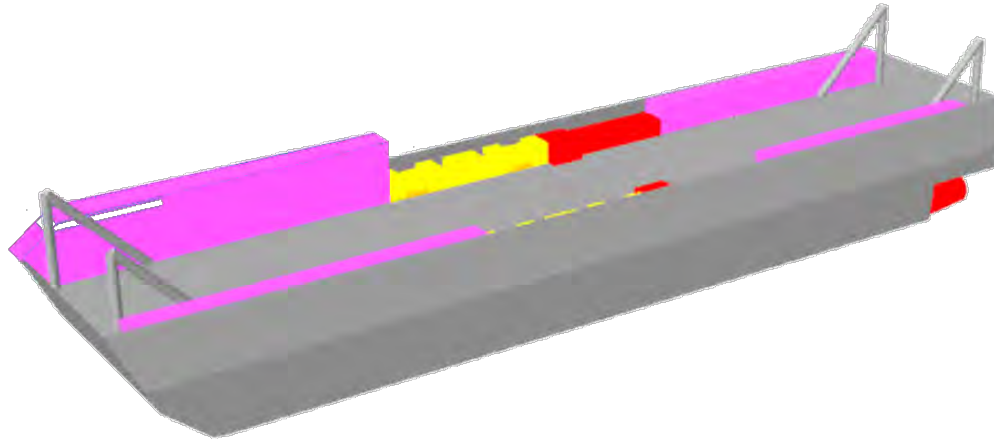
### Principal Characteristics

Length	m	67.3
Beam	m	15
Draft, on cushion	m	2.3
Speed	kts	25
Range	nm	2,500
Cargo Deck Area	m <sup>2</sup>	687
Self Deployment	days	30
Breakover Angle	degrees	4
Beach Gradient	%	2
Sea State Capacity	SS3	
Cargo Capacity	mt	300
Accommodations – Vehicle Operators		50
Accommodations – Crew		9-12
Full Load Displacement	mt	1566
Installed power	MW	24.9
Propulsion	MW	21.6
Lift	MW	3.3
Generating capacity	KW	315

Table 1: HLALC Characteristics

### General Arrangements

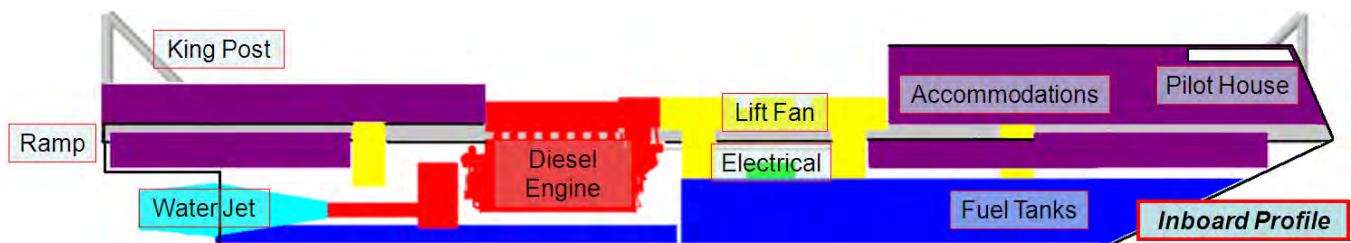
The HLALC concept design is a 67.3 m long steel PACSCAT. Shown in Figure 2, the HLALC consists of twin hulls with skirts at the bow and stern for the air cushion and an open cargo deck.



**Figure 2: Perspective View of HLALC**

### **Twin Hulls**

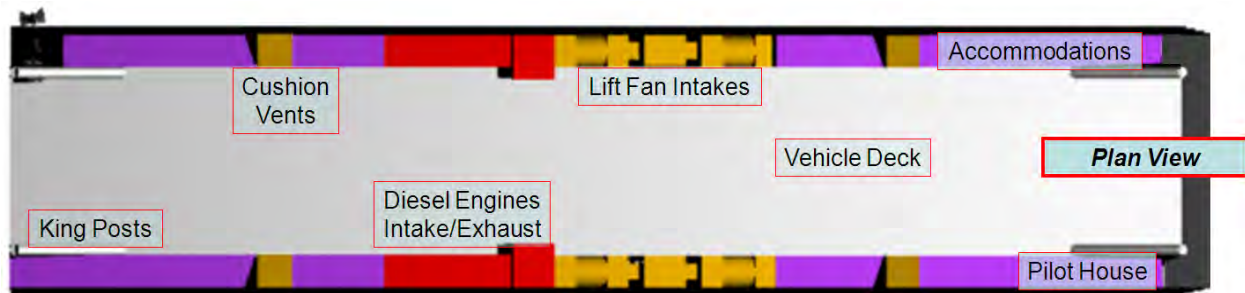
The twin hulls are 60.8 m in length and 3.5 m wide at the waterline. Located in the twin hulls are the propulsion system (engines, gearboxes and waterjets), accommodations spaces, auxiliary machinery, lift systems (engines, fans, ducts, etc) and fuel tanks. Figure 3 shows the layout of the equipment in the twin hulls.



**Figure 3: Inboard Profile Starboard Side Hull**

### **Cargo Deck**

The cargo deck runs the length of the HLALC. It is 67.3 m long and 10.5 m wide. The deck is open to facilitate loading/unloading of Lo/Lo cargo. The cargo deck has ample tiedown points to securely lash down cargo. Figure 4 is the plan view of the HLALC's cargo deck.



**Figure 4: Plan View of HLALC**

The air intakes for the lift fans and engines are also located on the cargo deck to provide protection from waves. The pilot house is located on the starboard side at the bow. This is to provide good visibility. Near the fore and aft ends of the cargo deck are kingposts which support the ramp during deployment and use.

## **Accommodations**

The accommodations of the HLALC support the crew of 9-12. These accommodations include berthing, storage, galley, mess, lounge, treatment systems, passageways, etc. The individual space allotments for the accommodations were derived from those used for the Mobile Landing Platform (MLP) ship which were based on Military Sealift Command (MSC) crew requirements. The total space required for accommodations was just under 200 m<sup>2</sup>.

## **Ramp**

The ramp system for the HLALC has been designed to meet and exceed the Army's requirements for break-over angle, length, and nearly dry delivery of vehicles on the beach. In keeping with the Army's desire for a simple robust design, the HLALC ramp system was designed as a one piece ramp. The ramp is based on a lightweight ramp proposed for the ONR T-Craft that was designed to military standards.\* The ramp material is carbon fiber which allows it to be light weight and extremely strong. Designed to weigh an estimated 25 mt, it is 60-70% lighter than an equivalent steel ramp and occupies about one third of the vertical space. At 6.5 m wide, it is a full width ramp. This keeps the ramp from becoming a bottleneck to cargo transfer operations. It is long enough (55 m) to reach over the water (at most beach gradients up to 1/25) to the beach, allowing vehicles and cargo to be delivered dry to the beach. At beach gradients up to 1/50, the ramp allows delivery of cargo through water less than 1 m deep.

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\* "TRILATERAL DESIGN AND TEST CODE FOR MILITARY BRIDGE AND GAP CROSSING EQUIPMENT" (January 2005)



The HLALC ramp configuration is unique in that there is only one ramp which is deployable from both the bow and stern. This allows great flexibility and saves the weight of carrying a second ramp. By being a solid one piece ramp, it simplifies construction, and eliminates the need for separate hydraulic systems to unfold and deploy the ramp(s). By stowing the ramp in a tunnel in the cross-deck structure, it keeps the vehicle deck area free of ramps and their deployment systems. It also keeps the ramps from obstructing the view from the pilothouse. This tunnel is lined with a series of rollers to drive (and guide) the constant cross section ramp from one end of the craft to the other. To deploy, the ramp would be powered out to a distance and stopped so that a crew member can attach support cables at the end of the ramp and mid-span. These cables run through the king posts located port and starboard of the bow and stern gates of the craft and are supported by winches located approximately 12 m from the king posts. The ramp would then be driven out to its full length and latched into place. A section of the deck would then be lowered to set the correct height interface between the ramp and the vehicle deck. Once the ramp is locked in place, the ramp foot would then be lowered to the beach using the winch. The cables are intended to stay connected to the ramp during operations. The mid-span cable can be sized to carry the loads required to support the center of the ramp to reduce the deflection and stress in the ramp while supporting movement of heavy cargo. The cables also serve as a visual guide to the drivers of the vehicles to locate the edges of the ramp. Appendix C shows the ramp deployment sequence.

The ramp and its deployment offer some interesting capabilities. Aside from delivering vehicles to the beach, it could also be used to link one HLALC to another (bow to stern) to create a beached causeway (beaching two HLALCs bow to stern), or to affect vehicle or personnel transfer between the HLALCs. This could be useful if one HLALC became disabled in the water. While these capabilities are intriguing, it should be noted that they would be limited by sea state and would require further analysis.

## **Propulsion**

### **Concept Design Drivers**

The dual mission profile for the HLALC established requirements for two similar yet different operating modes. Basic calculations showed that the deployment mission represented the more difficult operational case, and as such, was used to establish the sizing of the HLALC propulsive systems. Additionally, because of the chosen PACSCAT hullform, the propulsion plant had to be small enough to fit in the side-hull with adequate space for service.

## Powering Considerations

The first step in sizing the propulsion system was to establish an estimate of the total resistance that the propulsion system would have to overcome. A spreadsheet was developed to estimate the total resistance, propulsive coefficient, and power required at corresponding speeds by scaling available test data for a model of a 170-ton PACSCAT. Results of the calculations are shown in Figure 5.

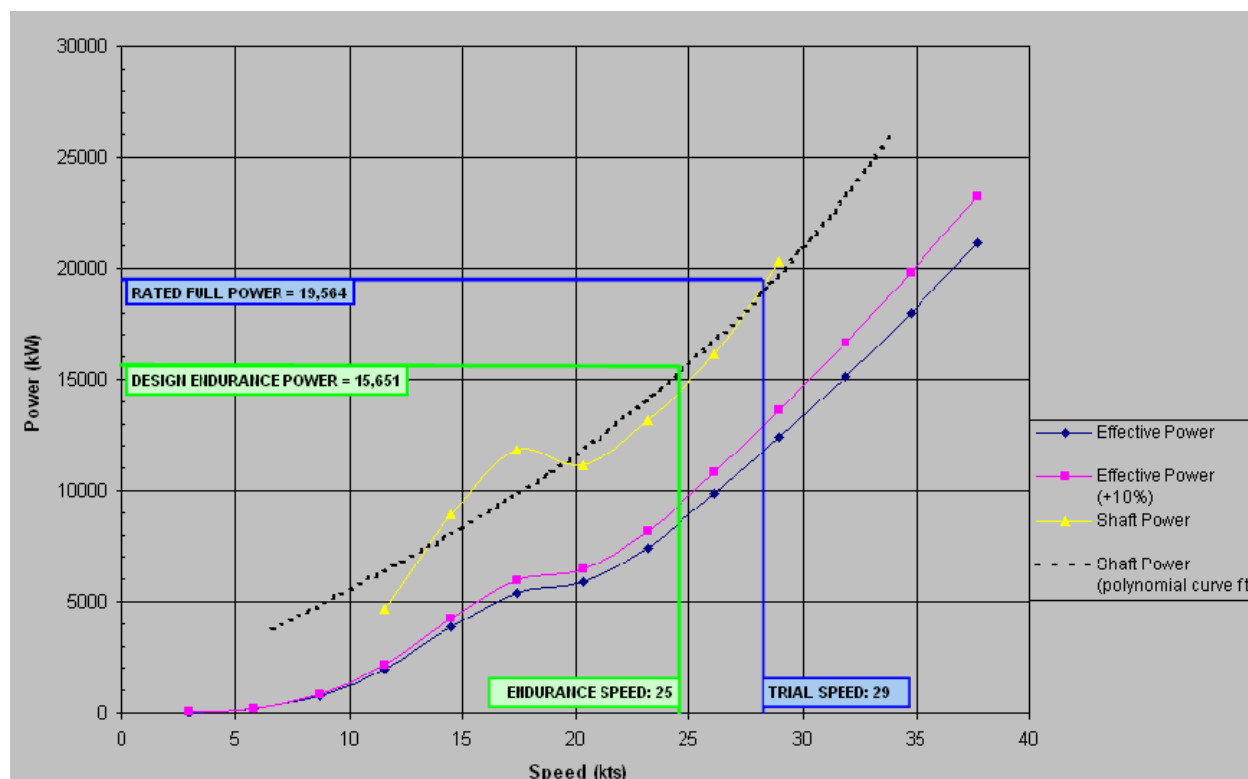


Figure 5: HLALC Powering Requirements

In accordance with the standard NAVSEA procedure for exploratory design, a 10% margin was applied to the calculated effective power. A curve fit was applied to the shaft power curve to facilitate calculation of the fuel load at any given speed between 6-32 kts. The figure shows that 15.6 MW is required for the design speed of 25 kts. Sustaining this speed requires 19.6 MW to be installed. The resulting trial speed is 29kts.

## Engine Selection

Two Wartsila 9L46F engines were selected as the main propulsive engines of the HLALC. The two provide a total of 21.6 MW. These 600 rpm engines were chosen because they exceed the HLALC's power requirement, and fit into the HLALC's side

hulls. It should also be noted that they have a specific fuel consumption of 0.171 kg/kW-hr, which is less than most of the other engines investigated.

Two Caterpillar 3516 diesels, providing a total power of 3.28 MW, were selected to power the four lift fans. Taking up 12.9 cubic meters, these 1800 rpm engines have a specific fuel consumption of 0.225 kg/kW-hr.

The propulsion engines and lift fan engines together give the HLALC a total installed power of 24.9 MW.

### **Propulsor Selection**

Waterjet propulsion system was chosen over propellers because they are more efficient at the speeds intended for the HLALC, they offer greater maneuverability, and they are less prone to damage during beaching operations. Two Lips LJ142E waterjets (2.4 m diameter) were chosen as the propulsion for the HLALC. They typically require less draft than other forms of propulsion, which also means that there is less chance for damage during beaching. Waterjets operate with high thrust at low speeds which is necessary when de-beaching. Waterjets operate at a higher RPM than propellers resulting in smaller reduction gears. In addition, they do not require a reversing gear.

## **Auxiliary systems**

### **Lift Fan Selection**

The sizing of the lift fans was based on scaling three existing PACSCAT concepts to accommodate the size of the HLALC. Needing a total flow rate of 1,012,541 m<sup>3</sup>/h, four Witt C Type PRZ medium-pressure centrifugal lift fans were chosen to lift the HLALC, with each fan providing 126,568 m<sup>3</sup>/h.

### **Generators**

The HLALC will have one Caterpillar 3406C generator set as the main generator to provide electrical power for the craft. A Caterpillar C6.6 ACERT generator set is provided as an emergency back-up generator should the main generator fail. The size of the main generator was scaled from the three existing PACSCAT concepts, yielding a required power of 270 kW. The emergency generator was sized to be 40% of the main generator, or 108 kW. The total generated power is 428 kW, with 315 kW supplied by the main generator and 113 kW in the emergency generator.

## Range and Fuel

Range for the HLALC deployment mission is 2,500 nm at 25 kts with the full 300 mt payload onboard. Therefore HLALC needs enough fuel to operate for 100 hours at 25 kts. While the 2,500 nm range is required in seaways through SS4, PACSCAT model test resistance data is only available through SS3 for a 170-ton PACSCAT hull form. As a result, HLALC seaway performance has been evaluated only through SS3.

The required fuel load was calculated in accordance with DDS-200. It was estimated that 417 mt of fuel is needed to meet the HLALC's deployment mission range requirement. Using this fuel load, a curve was plotted to show the ranges achievable at different speeds as shown in figure 6. The bottom curve of the lower band represents the range of the HLALC at a constant FLD with a full cargo load. However, SES's do not have seawater ballast systems to burn-off fuel and maintain constant displacement. This means that it is more reasonable to estimate the HLALC range using the Breguet method of approximating the effect of reduction in displacement due to fuel burn-off. The upper curve in the bottom band yields a more realistic Breguet-based estimate of the potential range achievable by the HLALC.

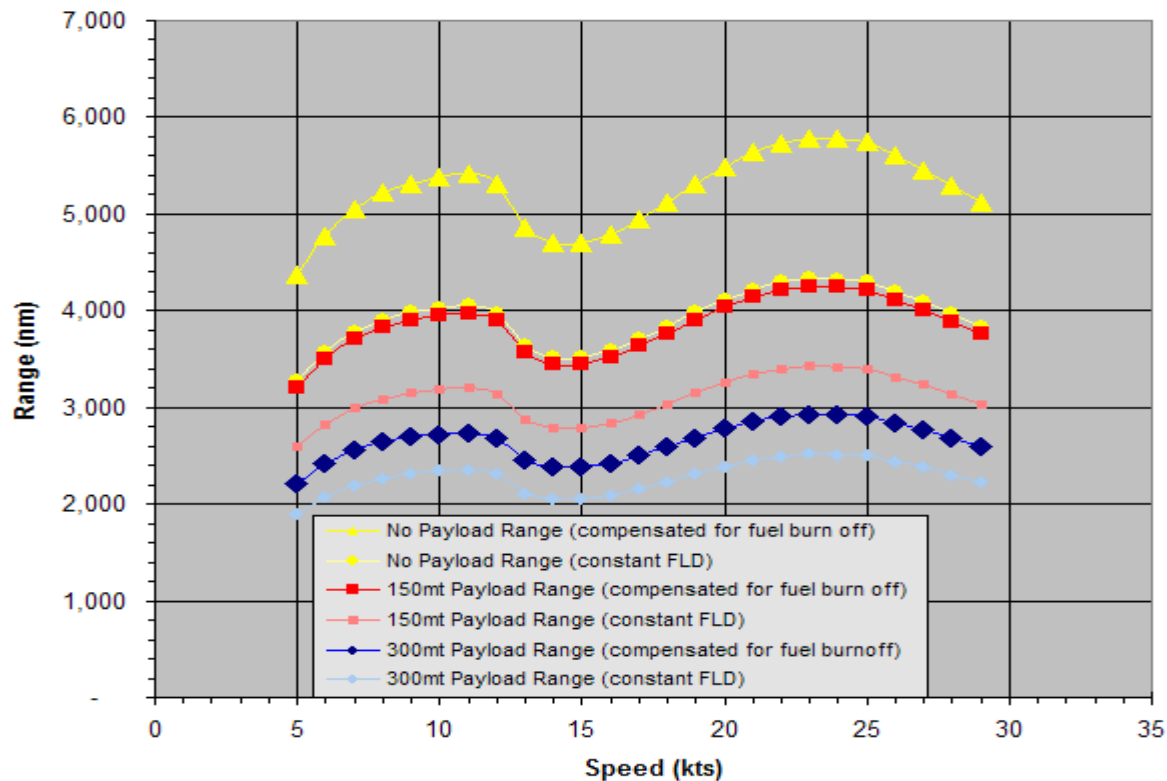


Figure 6: HLALC Operating Range

There are three sets of curves on the HLALC operating range chart. The lower bands of curves represent the variation in range baseline requirement of 2,500 nm, at 25 kts, with 300 mt payload. The figure shows that, regardless of payload, the HLALC has its greatest range when operated at a 23 kt speed. The HLALC has been designed with the fuel tank capacity to trade payload capacity for fuel load capacity to provide operational flexibility. This requires total fuel tank capacity for 717 mt of fuel. The second and third sets of curves show the ranges corresponding to the 150 mt payload, and in the unloaded condition respectively.

Figure 6 shows that the HLALC could self deploy fully loaded carrying 300 mt payload and at a speed of 23 kts, and travel over 2,900 nm. Likewise, if it were required to travel up to 4,250 nm, it could achieve that range by reducing the payload to 150 mt and taking on the extra weight in fuel. By trading all the payload capacity for fuel, the HLALC is estimated to have a maximum range of nearly 5,800 nm. This offers a great deal of flexibility to rapidly deploy and deliver assets where and when needed.

It may also be concluded that the current HLALC concept is probably over-designed in the areas of propulsion power and fuel load. During the next phase of design, the size of the propulsion system could probably be reduced to reduce ship size and cost. This potential reduction in the size of the propulsion system would have a cascading effect on many of the other ships systems.

## **Weight Estimation**

Lightship weight estimates for propulsion engines and waterjets were based on vendor data. The remaining lightship weights were parametrically scaled using data from the three PACSCAT designs. A 15% lightship weight margin was included. HLALC weights are summarized in Table 2. Weight estimate details are given in Appendix E.

<b>SWBS</b>	<b>Group</b>	<b>Weight (mt)</b>
100	Hull Structures	307
200	Propulsion Plant	383
300	Electrical Plant	10
400	Command and Control	1
500	Auxiliary Systems	11
600	Outfits and Furnishings	16
700	Armament	0
	<b>Lightship + margin</b>	<b>837</b>
	<b>Loads</b>	<b>728</b>
	-cargo	300
	-fuel	417
	-other	11
	<b>Full Load</b>	<b>1,565</b>

**Table 2: HLALC One-Digit Weight Summary**

## **Stability**

The HLALC's intact stability was evaluated using rough hydrostatic equations and simple shape assumptions. Worst case scenarios were used to compensate for approximations of dimensions and weights.

The calculations show that a fully loaded HLALC has a GM, the distance from the center of gravity to the transverse metacenter, of 10.4 m, which is about 73% of the beam at the design water line (DWL). Most monohull ships are designed to have a minimum transverse GM that is approximately 10% of the beam to achieve acceptable static stability combined with good seakeeping. The high GM to beam ratio of the HLALC assures good transverse stability, but may have a detrimental effect on seakeeping. A comprehensive seakeeping evaluation of the HLALC is recommended.

## **Conclusion**

### **Summary**

As the US military turns their attention to the future of landing craft and the replacement of those aging vessels, it is important to examine the current technologies to identify any gaps or short-comings in the present capabilities relative to current and projected functional needs. It is also important to review the present state of the art for

this type of craft. This project was the result of such an exercise. The Heavy Lift Army Landing Craft concept design utilizes the PACSCAT hull form, which is a variant of an SES. The HLALC concept design was developed to be a rugged, low maintenance landing craft that can deliver cargo to the shoreline at higher speeds with improved seakeeping. The HLALC concept is able to deliver various types of vehicles and cargo to and from beach areas as well as austere port facilities. It is also capable of long range self deployment. This will improve throughput for the sustainment mission.

## **Future Work**

In future iterations of the HLALC concept evolution several issues should be further examined.

The effects of sea states upon the craft need to be studied, especially the effects of sea state on speed, stability, and cargo transfer. These effects need to be studied further to determine the operational limits of the HLALC and to assess its Joint Operations capabilities.

The weight estimate should be refined along with the center of gravity of the design, as the design progresses. A more detailed analysis of the hull structure should be made to ensure the structural adequacy and validate the weight estimate.

A more detailed structural analysis should be done on the ramp. The ramp deployment system also requires further development

## **What We Learned**

The main purpose of the Naval Research Enterprise Intern Program (NREIP) is to develop naval engineers. This project successfully took a crew of mechanical engineers and taught them the basics of ship design.

The HLALC project team reviewed the design development work previously completed for the T-Craft project, particularly the new approaches that had been investigated. In addition, the mentors from the Center of Innovation in Ship Design (CISD) provided guidance from their valuable ship design experience to the group.

Lastly, we learned several principles of designing a ship concept from scratch. The first was to start working with reasonable assumptions based on past experience and similar vessels. This allowed the project to continually move forward and not get stuck at one phase. We also learned that the sooner the quantitative analysis begins the better the design can progress. Since design is an iterative process, more detailed

work will always come later and the initial assumptions will be confirmed or revised. A good example of this was the total ship size which we often changed due to better understanding of mission, new constraints from arrangements, changing margins, etc.

Overall this project was an excellent experience and will benefit each of the team members throughout their future careers. We wish to express our thanks at having been given the opportunity to work on this project, and we look forward to seeing what the future holds for the HLALC.



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# **Appendix A: Initial Brief**

## **Introduction**

1. The US Army, Navy and Marine Corp operate a range of smaller vessels which can be broadly described as Landing Craft (LC) designed for moving vehicles and cargo from ship to shore. Each service has, however, a different set of specific operation requirements and desirable capabilities.
2. Recent Navy LC programs have been focused on supporting over the horizon seabasing concepts and have focused on improving the overall speed and load capacity of LC. There is also a continuing desire for LC to be able to project beyond the shoreline and insert troops and equipment inland and critically dry. This is reflected in the current use of Landing Craft Air Cushion (LCAC – hovercraft) and in recent projects such as the T-Craft project, which has looked at alternative ways of designing fast sea-going vessels that can also operate as fully amphibious air cushion vehicles ashore.
3. The T-craft lift capabilities, range and speed are believed to be attractive to the Army, however the craft systems to support over the beach air cushioned operations are not necessary to meet the army's operational objectives, and are likely to incur unnecessary complexity and critical cost.
4. This project shall develop a concept LC to meet the Army's needs. It will be cognizant of the T-Craft program and some of the other future Landing Craft designs and concepts around the world in order to generate a viable design for the Army.

## **Aim**

5. Develop a baseline requirements set for a future Army LC – agree these with Army Sponsor;
6. Develop a viable concept design for a rugged, low maintenance landing craft to meet these requirements;
7. Assess the concept against navy and marine requirement sets to assess its 'joint service' utility.

## **Ship Design Requirements**

8. Proposed design must meet the following criteria:
  - a. Payload weight – 4 × M1A1 tanks (approximately 300 tonnes);
  - b. Payload deck area – 650 sq m equipped with suitable tie-down fittings and equipment;
  - c. Drive through cargo deck;
  - d. Maximum speed target of 25 knots with 250 nm range at maximum speed;
  - e. Sustained speed for maximum range of 14 knots; desired range 2,500 nm
  - f. Capable of delivering vehicles and troops dry to the beach and to austere ports;
  - g. Maneuverability suitable for beaching operations and working alongside at sea pontoons; ability to maintain slow speed loitering economically;
  - h. Must be self-deployable for 30 days;
  - i. Provide accommodations for 50 vehicle operators/troops during high speed operations;
  - j. Must support full range of Army combat and support land vehicles as well as palletized/containerized cargo.

## **Areas of Technology Exploration**

9. The design team is likely to investigate the following areas:
  - a. Non-conventional hullforms;
  - b. Propulsion systems;
  - c. Ramps and rapidly deployable causeways;
  - d. Lightweight structures;

## **Constraints**

10. The report and design shall be unclassified, including all supporting analysis and data amended as necessary.

## **Approach**

11. The competing ideas shall be reduced to a preferred concept using a decision making process.
12. A system design synthesis model shall be developed. A complete system synthesis shall be undertaken. A balanced design shall result with a corresponding performance analysis.
13. The implications of any new technology or operational issues shall be noted. Recommendation for follow on work shall be documented.

## **Deliverables**

14. All work will be documented in a CISC Project Technical Report. The final report and presentation shall be suitable for unclassified, public release.
15. During the first 2 weeks the team will produce a team project plan of actions, assignments and milestones to be presented to CISC leadership for approval. During the project this plan shall be maintained.
16. The team will develop and give informal intermediate presentations and a final project presentation.
17. The resulting design shall be detailed including a single sheet summary of characteristics including estimated performance, a comprehensive SWBS breakdown, an area/volume summary, and design drawings.
18. The team will be encouraged to produce a technical paper from the final report suitable for publishing at a professional society conference.

## Appendix B: PACSCAT Reference Data

		FLC Concept A	FLC Concept B	HSC
Length	m	28.3	42.6	128.0
Beam	m	8.5	12.5	28.0

	FLC Concept A			FLC Concept B			HSC		
	mt	LCG	VCG	mt	LCG	VCG	mt	LCG	VCG
Group 100	59.4	13	1.9	112.2	20.5	2.2	1149		
111	21.8	13	1.5	43.1	20.5	1.7	341	62	4
116	8.6	13	1.5	16.3	20.5	1.7	334	56	5
118	4.2	13	3	13.7	20.5	3.5	14	118	9
119	1.7	13	1.2	2.8	20	1.2	14	20	3
121	3.3	13	2	5.6	20.5	2	44	60	4
122	3.8	13	1.5	7.2	20.5	1.7	34	50	4
130	7.8	13	2.5	13.6	20.5	3			
131							194	64	7
140							15	8	4
150	0.3	6	4.5	0.3	6	5	98	75	11
159							6	110	13
162	0	0	0	0	0	0	18	38	10
163	0	0	0	0	0	0			
165	0	0	0	0	0	0			
167	5.6	13.5	4	6.4	20.5	4	25	120	6
168							3	28	10
170	0.1	4	5.5	0.1	4	5.5	2	105	16
182	1.5	13.5	0.5	2	19	0.5	4	38	1.5
183	0.2	15	0.5	0.3	25	0.5	1	60	2
185	0.5	18.5	1.5	0.8	32	2	2	55	3
190	0	0	0	0	0	0	0	0	0
199	0	0	0	0	0	0			
Group 200	30.5	10.3	1.3	54	14.5	1.7	302		
233	16.8	12.5	1.5	30.2	16.5	2	18	60	5
234	0	0	0	0	1	0	54	38	2.5
241	2.9	9.5	1	5.4	14	1.2	60	35	2
242	0.3	9	1	0.5	13.5	1.2	8	34	2
243	0.2	7.5	1	0.3	10	1	10	23	2
244	0.2	7.5	1	0.3	10	1	6	24	2
245	0	0	0	0	0	0	0	0	0

	FLC Concept A			FLC Concept B			HSC		
	mt	LCG	VCG	mt	LCG	VCG	mt	LCG	VCG
247	7.3	3	1	12.1	3.7	1	102	4	2
248	2	20.5	1.7	6	34	3	12	53	5
251	0.2	10	2	0.6	14	2.5	8	40	8
252	0.1	14	1.5	0.1	18	2	2	39	4
256	0.2	12	1	0.3	16	1	2	60	2
259	0.1	12	1	0.1	15	2	12	39	8
261	0.1	13	2	0.1	18	2	6	40	4
264	0.1	13	1.5	0.2	18	2	2	40	4
290	0	0	0	0	0	0	0	0	0
299	0	0	0	0	0	0	0	0	0
Group 300	3.1	14.2	1	3.4	22.8	1	34		
311	2	15	1	2	25	1	10	60	3
312	0.2	7	1.5	0.2	7	1.5	2	5	5
313	0.5	15	0.5	0.5	25	0.5	2	60	2
314	0.1	15	1	0.2	25	1	2	60	3
320	0.2	12	2	0.3	15	2	8	75	6.5
324	0.1	15	1.5	0.1	25	1.5	2	60	3
330	0	0	0	0	0	0	5	75	6.5
342	0.1	14	1.5	0.1	18	1.5	1	60	5
343	0	0	0	0	0	0	2	40	4
399	0	0	0	0	0	0	0	0	0
Group 400	0.5	7	4	0.5	7	4.7	11		
410	0.1	7	4	0.1	7	4.5	4	113	13
420	0.1	7	4	0.1	7	4.5	1	96	13
430	0	0	0	0	0	0	1	103	13
440	0.1	7	4	0.1	7	4.5	1	100	13
451	0.2	7	4	0.2	7	5	2	96	13
452	0	0	0	0	0	0	0	0	0
455	0	0	0	0	0	0	0	0	0
461	0	0	0	0	0	0	0	0	0
462	0	0	0	0	0	0	0	0	0
471	0	0	0	0	0	0	0	0	0
474	0	0	0	0	0	0	0	0	0
475	0	0	0	0	0	0	0	0	0
476	0	0	0	0	0	0	0	0	0
481	0	0	0	0	0	0	0	0	0
482	0	0	0	0	0	0	0	0	0

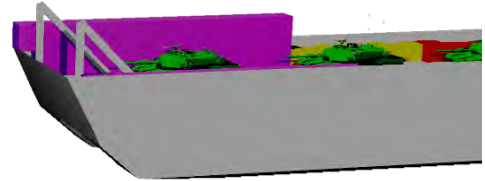
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483	0	0	0	0	0	0	0	0	0
492	0	0	0	0	0	0	1	31	12
494	0	0	0	0	0	0	1	102	13
Group 500	4.4	11.3	2.2	6.6	17.5	2.4	64		
510	0.2	6	3	0.2	6	3.5	4	62	3
514	0.1	6	3	0.1	6	3.5	4	61	3
521	0	0	0	0	0	0	8	58	3
530	0.1	0.1	3	0.1	3.5	3.5	2	61	1
541	0.1	0.1	2.5	0.1	20	2.5	3	40	3
543	0	0	0	0	0	0	2	54	2
551	0	0	0	0	0	0	3	40	3
555	0.4	0.4	2	0.6	18	2.5	2	65	6
556	1.5	1.5	1.5	2.2	20	1.5	3	80	6
560	0.3	0.3	1	0.6	2	1	4	2	2
565	0.2	0.2	2	0.4	20	2.5	2	45	5
571	0	0	0	0	0	0	2	30	7
581	0.2	0.2	3.5	0.4	1	4	10	120	7
582	1.2	1.2	3	1.8	26	3.5	3	118	7
583	0	0	0	0	0	0	6	6	7
588	0	0	0	0	0	0	4	40	7
592	0	0	0	0	0	0	0	0	0
593	0.1	0.1	2.5	0.1	3	2.5	2	90	1
Group 600	5.5	11.2	2.5	8.2	16.2	2.9	129		
611	2.8	14	2.7	4.2	22	3.2	25	55	7
621	0.4	6	3	0.5	6	3.5	14	65	5
624	0.2	8	2	0.3	8	2.5	5	65	5
631	0.2	14	2	0.4	24	2.5	4	60	4
633	0.1	4	0	0.1	4	0	2	30	1
634	0.2	15	2.5	0.3	24	3	18	65	4
635	1.2	8	2	2	8	2.5	12	53	5
641	0	0	0	0	0	0	5	80	5
642	0.2	6	3	0.2	6	3.5	10	70	5
643	0	0	0	0	0	0	20	70	5
644	0.1	3	4	0.1	3	4.5	5	60	5
652	0	0	0	0	0	0	1	37	5
654	0	0	0	0	0	0	1	36	5
656	0	0	0	0	0	0	1	36	5



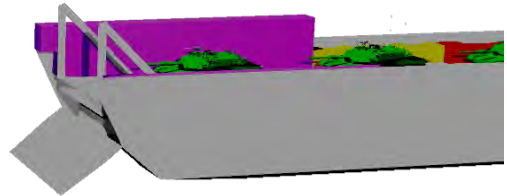
	FLC Concept A			FLC Concept B			HSC		
	mt	LCG	VCG	mt	LCG	VCG	mt	LCG	VCG
660	0	0	0	0	0	0	1	15	5
664	0	0	0	0	0	0	1	60	5
665	0	0	0	0	0	0	2	14	5
672	0.1	14	3	0.1	10	3.4	2	18	5
Group 700	0	0	0	0	0	0	10		
711	0	0	0	0	0	0	4	123	9
713	0	0	0	0	0	0	2	53	2
721	0	0	0	0	0	0	0	0	0
723	0	0	0	0	0	0	0	0	0
730	0	0	0	0	0	0	0	0	0
740	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0
760	0	0	0	0	0	0	1	110	13
780	0	0	0	0	0	0	3	46	8
799	0	0	0	0	0	0	0	0	0
Group F	84.4	12.5	2.5	162	18.3	4.1	1486		
F11	0	0	0	0	0	0	5	80	5
F12	0.1	6	4	0.3	6	4.5	10	70	5
F13	0	0	0	0	0	0	25	70	5
F21	0	0	0	0	0	0	10	53	2
F23	0	0	0	0	0	0	22	37	8
F31	0.2	5	4	0.2	5	4.5	20	18	5
F32	0	0	0	0	0	0	5	36	5
F41	17	15	2	28	20.5	2.5	500	55	5.5
F43	0	0	0	0	0	0	100	53	2
F46	0.2	14	1	0.4	18	1.5	6	35	5
F52	0.1	4	3	0.1	4	3.5	50	85	1
F54	0.4	15	2	0.8	22	2.5	5	80	7
F55	0.1	3	3	0.1	3	3	2	90	1
F60	66.1	12	4	132.2	18	4.5	726	80	9
Lightship	103.4			184.9			1699		
Margins	16			28.6			263		
FLD	203.8			375.5			3448		

## Appendix C: Ramp Deployment

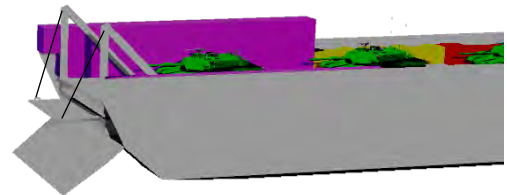
**Step 1)** HLALC beaches itself and comes off cushion.



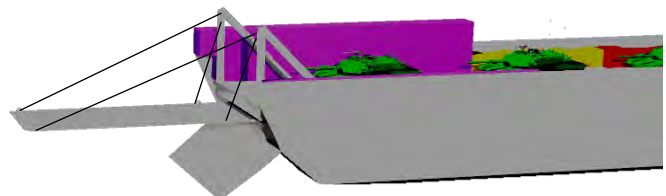
**Step 2)** HLALC gate drops and prepares for ramp to deploy.



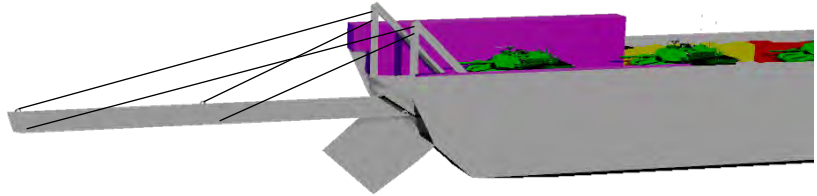
**Step 3)** HLALC ramp advances to access ramp foot cable connection points where crew member attaches cables to support ramp foot.



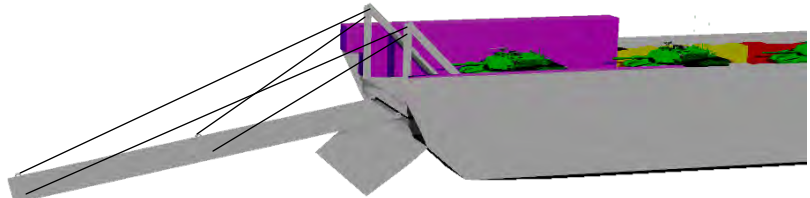
**Step 4)** HLALC ramp advances to access ramp mid-point cable connections where crew member attaches cables to support mid ramp.



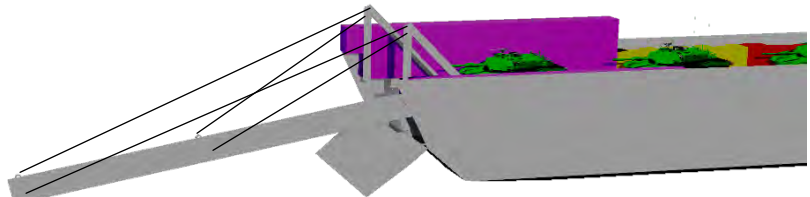
**Step 5)** HLALC ramp advances to full extent supported by cables to maintain alignment with ramp tunnel and latches in place.



**Step 6)** HLALC ramp lowers to beach by ramp cables. Cables remain attached to ramp.



**Step 7)** HLALC deck section lowers to interface with ramp at correct height. Ramp is now ready for use.



## Appendix D: Personnel Space Requirements

(based on Mobile Landing Platform requirements for Military Sealift Command crew)

GA Space Requirements							
Space Name	Min. Area (Each)		qty	Min. Area (total)		Notes (AHLC)	Remarks (MLP)
	m2	ft2	req'd	m2	ft2		
Chief Petty Officer (CPO) Private T/S	2.0	21.5	4	8.0	86.1	one per each 3-person bunkroom	one per each 3-person bunkroom
Chief Petty Officer (CPO) 3-Person Bunkroom	11.1	119.5	4	44.4	477.9	one bunkroom for officers; three bunkrooms for crew	
Linen Locker (Clean)	1.1	12.0	2	2.2	24.0	probably need space for two on 30 day mission	2.3m2
Linen Locker (Dirty)	1.1	12.0	2	2.2	24.0	probably need space for two on 30 day mission	2.3m2
CBR-D Equipment Storeroom	4.8	52.0	1	4.8	52.0	one req'd scaled down from MLP	8.5 m2 and 2 req'd
Cleaning Gear Locker	2.3	24.8	1	2.3	24.8	one located on main deck	
Foul Weather Gear Locker	4.5	48.0	1	4.5	48.0		5m2 - 6 req'd
Small Arms Magazine	2.0	21.5	1	2.0	21.5	for vessel security	19 m2 req'd for 454 troops plus LCAC operator crews
Troop Seabag Stowage	4.0	43.1	1	4.0	43.1	separate from quarters	was 20m2 each and 4-5 req'd
Trash Room	2.0	21.5	1	2.0	21.5		30m2
Bakery		0.0		0.0	0.0	included in galley	Include in Galley
Embarked CPO/SNCO Messroom	13.0	140.0	1	13.0	140.0	for 12 diners	33m2
Embarked Personnel CPO/SNCO Lounge	13.0	140.0	1	13.0	140.0	located adjacent to messroom - can be partitioned off or opened up for	Shall be capable of being partitioned off from the mess room.

						conference room space	
Embarked Personnel Daily Provision Storeroom	2.2	24.0	1	2.2	24.0	estimated	6.7m2
Embarked Personnel Dry Provision Storeroom	3.0	32.0	1	3.0	32.0	estimated	
Embarked Personnel Galley	20.1	216.0	1	20.1	216.0	scaled down	163m2 - One dedicated serving line shall be provided for Officers. Two dedicated serving lines shall be provided for CPO/SNCO and Enlisted personnel
Officer/CPO/SNCO Scullery	6.5	70.0	1	6.5	70.0	adjacent to lounge - scaled down	23.2m2
Embarked Personnel CPO/SNCO Self-Service Laundry	7.4	80.0	1	7.4	80.0		16.3m2
Physical Fitness Space	10.4	112.0	1	10.4	112.0		62m2 - Space may be divided in two spaces of similar area.
Deck Head	1.9	20.0	3	5.6	60.0	one near pilot house one on vehicle deck one on machinery deck	2.6m2 - 2 on each deck
Decontamination Station	1.4	15.0	1	1.4	15.0		13m2 each - 2 req'd
Subtotal				159.0	1711.9		
5% For Unassigned (margin)				8.0	85.6		
10% For Fan Rooms (ventilation)				15.9	171.2		
10% For Passageways (lower decks only)				15.9	171.2	mission deck functions as passageway on main deck level	15% for passageways (all decks)
<b>Total</b>				<b>198.8</b>	<b>2139.9</b>		

## Appendix E: HLALC Detailed Weight Breakdown

WEIGHTS	SWBS GROUP	mt
<b>W100</b>	<b>HULL STRUCTURES</b>	<b>341.3</b>
W110	SHELL + SUPPORTS	<b>129.7</b>
W111	PLATING	61.0
W116	LONGIT FRAMING	47.0
W118	Bulwarks	14.7
W119	Bow and Stern Seals	7.0
W120	HULL STRUCTURAL BULKHDS	<b>24.7</b>
W121	LONGIT STRUCTURAL BULKHDS	12.6
W122	TRANSV STRUCTURAL BULKHDS	12.1
W130	HULL DECKS	<b>162.0</b>
W131	MAIN DECK	100.0
	WET DECK	62.0
W140	HULL PLATFORMS/FLATS	<b>1.9</b>
W150	DECK HOUSE STRUCTURE	<b>11.4</b>
W160	SPECIAL STRUCTURES	<b>9.0</b>
W162	STACKS AND MACKS	2.3
W167	HULL STRUCTURAL CLOSURES	6.3
W168	DKHS STRUCTURAL CLOSURES	0.4
W170	MASTS+KINGPOSTS+SERV PLATFORM	<b>0.3</b>
W180	FOUNDATIONS	<b>2.3</b>
W182	PROPULSION PLANT FOUNDATIONS	1.5
W183	ELECTRIC PLANT FOUNDATIONS	0.3
W185	AUXILIARY SYSTEMS FOUNDATIONS	0.6
<b>W200</b>	<b>PROPULSION PLANT</b>	343.9
W230	PROPULSION UNITS	<b>291.3</b>
W233	DIESEL ENGINES	275.5
W237	AUXILIARY PROPULSION DEVICES	15.8
W240	TRANSMISSION+PROPULSOR SYSTEMS	<b>48.4</b>
W241	REDUCTION GEARS	9.3
W242	CLUTCHES + COUPLINGS	1.1
W243	SHAFTING	1.3
W244	SHAFT BEARINGS	0.8
W247	WATER JET PROPULSORS	28.0
W248	Lift fans and ducting	7.8
W250	SUPPORT SYSTEMS	<b>3.2</b>
W251	COMBUSTION AIR SYSTEM	1.1
W252	PROPULSION CONTROL SYSTEM	0.3
W256	CIRC + COOL SEA WATER SYSTEM	0.4

W259	UPTAKES (INNER CASING)	1.4
W260	PROPUL SUP SYS- FUEL, LUBE OIL	<b>1.0</b>
W261	FUEL SERVICE SYSTEM	0.7
W264	LUBE OIL HANDLING	0.3
<b>W300</b>	<b>ELECTRIC PLANT, GENERAL</b>	<b>6.3</b>
W310	ELECTRIC POWER GENERATION	<b>5.0</b>
W311	SHIP SERVICE POWER GENERATION	2.5
W312	EMERGENCY GENERATORS	1.6
W313	BATTERIES+SERVICE FACILITIES	0.5
W314	POWER CONVERSION EQUIPMENT	0.3
W320	POWER DISTRIBUTION SYS	<b>1.1</b>
W324	SWITCHGEAR+PANELS	0.3
W340	POWER GENERATION SUPPORT SYS	<b>0.2</b>
W342	DIESEL SUPPORT SYS	0.2
<b>W400</b>	<b>COMMAND &amp; CONTROL</b>	<b>1.2</b>
W410	COMMAND+CONTROL SYS	<b>0.5</b>
W420	NAVIGATION SYS	<b>0.2</b>
W440	EXTERIOR COMMUNICATIONS	<b>0.2</b>
W450	SURF SURV SYS (RADAR)	<b>0.3</b>
W451	SURFACE SEARCH RADAR	0.3
<b>W500</b>	<b>AUXILIARY SYSTEMS, GENERAL</b>	<b>9.9</b>
W510	CLIMATE CONTROL	<b>0.6</b>
W514	AIR CONDITIONING SYSTEM	0.6
W520	SEA WATER SYSTEMS	<b>1.0</b>
W521	FIREMAIN+SEA WATER FLUSHING SYS	1.0
W530	FRESH WATER SYSTEMS	<b>0.3</b>
W540	FUELS/LUBRICANTS,HANDLING+STORAGE	<b>0.7</b>
W541	SHIP FUEL+COMPENSATING SYSTEM	0.4
W543	AVIATION+GENERAL PURPOSE LUBO	0.3
W550	AIR,GAS+MISC FLUID SYSTEM	<b>2.3</b>
W551	COMPRESSED AIR SYSTEMS	0.4
W555	FIRE EXTINGUISHING SYSTEMS	0.5
W556	HYDRAULIC FLUID SYSTEM	1.4
W560	SHIP CNTL SYS	<b>0.7</b>
W565	TRIM+HEEL SYSTEMS	0.4
W570	UNDERWAY REPLENISHMENT SYSTEMS	<b>0.3</b>
W571	REPLENISHMENT-AT-SEA SYSTEMS	0.3
W580	MECHANICAL HANDLING SYSTEMS	<b>3.8</b>
W581	ANCHOR HANDLING+STOWAGE SYSTEMS	1.3
W582	MOORING+TOWING SYSTEMS	1.2
W583	BOATS,HANDLING+STOWAGE SYSTEMS	0.8

W588	AIRCRAFT HANDLING,SERVICE,STOWAGE	0.5
W590	SPECIAL PURPOSE SYSTEMS	<b>0.3</b>
W593	ENVIRONMENTAL POLLUTION CNTL SYS	0.3
<b>W600</b>	<b>OUTFIT+FURNISHING,GENERAL</b>	<b>25.9</b>
W610	SHIP FITTINGS	<b>4.9</b>
W611	HULL FITTINGS	4.9
W620	HULL COMPARTMENTATION	<b>3.9</b>
W621	NON-STRUCTURAL BULKHEADS	2.9
W624	NON-STRUCTURAL CLOSURES	1.0
W630	PRESERVATIVES+COVERINGS	<b>15.0</b>
W631	PAINTING	2.0
W633	CATHODIC PROTECTION	1.0
W634	DECK COVERINGS	8.0
W635	HULL INSULATION	4.0
W640	LIVING SPACES	<b>1.8</b>
W642	NON-COMM OFFICER B+M	1.3
W644	SANITARY SPACES+FIXTURES	0.5
W670	STOWAGE SPACES	<b>0.3</b>
W672	STOREROOMS+ISSUE ROOMS	0.3
	<b>LIGHTSHIP</b>	<b>728.4</b>
M11	DESIGN + BUILDING MARGINS	<b>109.3</b>
	<b>LIGHTSHIP + Margin</b>	<b>837.6</b>
F10	SHIPS FORCE	<b>1.3</b>
F12	NON-COMMISSIONED OFFICERS	1.3
F30	STORES	<b>2.4</b>
F31	PROVISIONS+PERSONNEL STORES	2.4
F40	LIQUIDS, PETROLEUM BASED	<b>417.9</b>
F41	FUEL OIL	417.0
F46	LUBRICATING OIL	0.9
F50	LIQUIDS, NON-PETRO BASED	<b>7.0</b>
F52	FRESH WATER	5.8
F54	HYDRAULIC FLUID	0.9
F55	SANITARY TANK LIQUID	0.3
F60	CARGO	<b>300.0</b>
<b>F00</b>	<b>TOTAL VARIABLE LOADS</b>	<b>728.6</b>
	<b>TOTAL - FULL LOAD DISPLACEMENT</b>	<b>1566.2</b>